The eastern Amessoui Syncline – a hotspot for Silurian to Carboniferous cephalopod research

Klug, Christian ; Pohle, Alexander

Abstract: Introduction : The Moroccan eastern Anti-Atlas comprises two large regions with vast outcrops of Palaeozoic rocks, the Maïder and Tafilalt (HOLLARD 1967, 1970, 1974), which have become world-reknown for Palaeozoic cephalopods, trilobites, and other groups (e.g. TERMIER TERMIER 1950; MASSA 1965). Palaeogeographically, these regions correspond to the Maïder and Tafilalt Basins, which are divided by the south-north running Tafilalt Platform (WENDT et al. 1984; WENDT 1985, 1988; BAIDDER et al. 2016). This platform was submerged throughout the Silurian to Early Carboniferous and is characterized by often condensed, highly fossiliferous sedimentary sequences. Especially the Devonian succession (Fig. 1) crops out in a series of east-west oriented synclines. The largest of which was dubbed Amessoui Syncline after the mountain Jebel Amessoui (Fig. 2). At the western end of this syncline, the Devonian succession is much thicker than in the east because it was situated on the slope toward the Maïder Basin. In the eastern half of the syncline, the Middle to Late Devonian succession is much reduced in thickness because of the position on the Tafilalt Platform. The localities El Atrous, Filon 12, Jebel Ouaoufilal, Takkat Ou El Heyene, and El Khraouia are all situated on the former platform and accordingly are rich in pelagic fossil communities, especially cephalopods. In many layers, cephalopods occur in nearly rock-forming numbers, which can be considered as Konzentratlagerstätte sensu SEILACHER (1970, 1990). Here, we provide an overview of the cephalopod occurrences in the eastern Amessoui Syncline in their stratigraphic context.

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The eastern Amessoui Syncline – a hotspot for Silurian to Carboniferous cephalopod research

CHRISTIAN KLUG [1] & ALEXANDER POHLE [1]

Fig. 1: The eastern Amessoui Syncline between Filon 12 and the Jebel Ouaoufilal: This photo was taken standing on the condensed Middle Devonian looking towards the northeast. The ridge beneath the rainbow is composed of Late Devonian sediments. The valley yields mainly haematitic ammonoids from the Givetian. The dark band in the middle of the slope is the Frasne Event Bed, the dark limestones near the crest correspond to the Kellwasser interval, and the brownish limestones on the crest are of early Famennian age (mostly *Phoenixites frechi* Zone).

Highlights

- **Late Silurian *Temperoceras* Limestone.**
- **Silurian/ Devonian boundary with orthocerid limestones.**
- **Lochkovian orthocerid nodules.**
- **Pragian rise in benthic diversity with diverse orthocerids.**
- **Abundant earliest Emsian Faunule 1 with numerous bactritids and orthocerids.**
- **Giant actinocerids of the late early Emsian.**
- **Late Emsian anarcestids.**
- **Strongly condensed Eifelian sequence rich in ammonoids and other cephalopods.**
- **Haematitic early Givetian ammonoid fauna.**
- **Haematitic faunas of the middle and late Famennian.**
- **Diverse trace fossils in the Tournaisian.**
- **Diverse Tournaisian ammonoid assemblage.**

1. Introduction

The Moroccan eastern Anti-Atlas comprises two large regions with vast outcrops of Palaeozoic rocks, the Maïder and Tafilalt (HOLLARD 1967, 1970, 1974), which have become world-reknown for Palaeozoic cephalopods, trilobites, and other groups (e.g. TERMIER & TERMIER 1950; MASSA 1965). Palaeogeographically, these regions correspond to the Maïder and Tafilalt Basins, which are divided by the south-north running Tafilalt Platform (WENDT et al. 1984; WENDT 1985, 1988; BAIDDER et al. 2016). This platform was submerged throughout the Silurian to Early Carboniferous and

[1] Prof. Dr. Christian Klug, M.Sc. Alexander Pohle, Paläontologisches Institut und Museum, Universität Zürich, Karl Schmid-Strasse 4, CH-8600 Zürich, Switzerland, chklug@pim.uzh.ch, alexander.pohle@pim.uzh.ch

is characterized by often condensed, highly fossiliferous sedimentary sequences. Especially the Devonian succession (Fig. 1) crops out in a series of east-west oriented synclines. The largest of which was dubbed Amessoui Syncline after the mountain Jebel Amessoui (Fig. 2). At the western end of this syncline, the Devonian succession is much thicker than in the east because it was situated on the slope toward the Maïder Basin. In the eastern half of the syncline, the Middle to Late Devonian succession is much reduced in thickness because of the position on the Tafilalt Platform. The localities El Atrous, Filon 12, Jebel Ouaoufilal, Takkat Ou El Heyene, and El Khraouia are all situated on the former platform and accordingly are rich in pelagic fossil communities, especially cephalopods. In many layers, cephalopods occur in nearly rock-forming numbers, which can be considered as Konzentratlagerstätte sensu SEILACHER (1970, 1990). Here, we provide an overview of the cephalopod occurrences in the eastern Amessoui Syncline in their stratigraphic context.

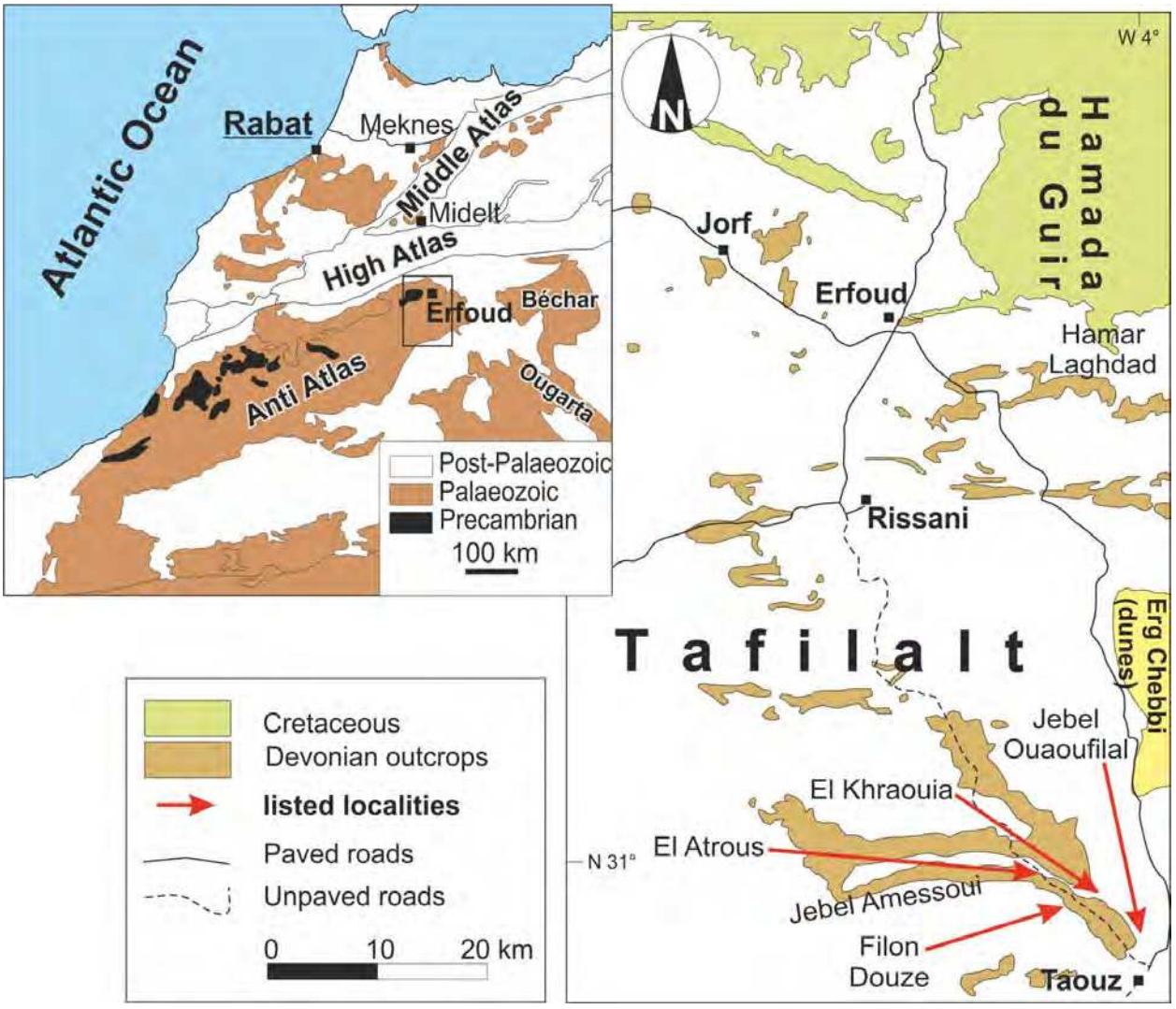

Fig. 2: Map of Morocco (northern Provinces) and the Tafilalt location (modified after KLUG 2002 and KLUG et al. 2016).

2. Research history

The Amessoui Syncline is probably slightly less well explored than the northern Tafilalt, with the famous localities of Bou Tchrafine and Hamar Laghdad (see their chapters in this volume). For the first decades of stratigraphic and palaeontological research, we refer to these, since there is a rather big overlap. An incomplete overview of the last decades of cephalopod-related research is given in the subsequent paragraphs.

PETTER (1959): This is the classic, pioneering monograph on Devonian ammonoids from Morocco and Algeria.

HOLLARD (1963): First report of earliest Emsian ammonoids from the entire Anti-Atlas including a specimen from N of Chaib Er Ras.

HOLLARD (1974): Important pioneering work with numerous sections from the eastern Anti-Atlas, including several from the Amessoui Syncline.
MASSA (1965): Important pioneering work depicting numerous sections from the eastern Anti-Atlas with their carbonate and fossil content, including several from the Amessoui Syncline.
BECKER et al. (1989): Short paper on the Late Devonian succession at El Atrous.
WENDT & BELKA (1991): This article is dedicated to the Kellwasser Event-related deposits in the Anti-Atlas, incorporating data from several sections in the Amessoui Syncline.
KORN (1999): Famennian ammonoid stratigraphy including specimens from the Amessoui Syncline.
BULTYNCK & WALLISER (2000): They discuss Devonian boundaries, including sections from the eastern Amessoui Syncline.
KLUG et al. (2000): Early and Middle Devonian ammonoid and conodont stratigraphy in the eastern Amessoui Syncline.
KORN et al. (2000): Late Devonian ammonoid and conodont stratigraphy in the eastern Amessoui Syncline.
KLUG (2001): Early Emsian sections including their ammonoid content.
KLUG (2002a, b): Late Emsian to Eifelian sections including their ammonoid content.
KORN et al. (2002, 2003): Tournaisian ammonoid assemblages from the eastern Amessoui Syncline.
KLUG et al. (2008): Description of early Emsian faunules (mostly invertebrates, many cephalopods) including those from the *Devonobactrites* Shale of the Amessoui Syncline.
KRÖGER (2008): Important monograph with descriptions of nautiloids from the eastern Amessoui Syncline.
HARTENFELS & BECKER (2009): Documentation of the Dasberg Event including localities from the eastern Amessoui Syncline. They list both conodonts and ammonoids.
DE BAETS et al. (2010b, 2015): Description of Early to Middle Devonian ammonoids with Housean pits including late Emsian to early Givetian specimens from the eastern Amessoui Syncline.
KLUG et al. (2010a): Description of a nonagonal orthocerid from the late Emsian of the Amessoui Syncline.
KAISER et al. (2011, 2013, 2015): A series of papers dedicated to the Hangenberg Event and the Devonian-Carboniferous boundary including sections and data from the Amessoui Syncline.
ABOUSSALAM & BECKER (2011): Study on the global Taghanic Crisis in the Tafilalt, with some data on the Amessoui Syncline.
KORN et al. (2011): Frasnian beloceratids, including specimens from the Amessoui Syncline.
HARTENFELS (2011): Investigation of the *Annulata* and Dasberg Crisis Intervals at Jebel Ouaoufilal and El Atrous East.
BECKER et al. (2013): Field guide book providing stratigraphic details of the Early and Middle Devonian of NW of El Khraouia.
HARTENFELS et al. (2014): Field guide book providing stratigraphic details of the Upper Devonian of NW of El Khraouia.
KLUG et al. (2013): Field guide book providing stratigraphic details of the Early and Middle Devonian of the SE part of the Amessoui Syncline.
KLEIN & KORN (2014): Several new species of *Cymaclymenia* including specimens from the eastern Amessoui Syncline.
BENHARREF et al. (2015a, 2015b): New geological maps (1 : 50 000), sheets Al Atrous and Marzouga, with new biostratigraphy data and fossil illustrations by ABOUSSALAM & BECKER (2015).
ABOUSSALAM et al. (2015): Revision of mostly Emsian conodont biostratigraphy including some ammonoid data.
KLUG et al. (2015a): Study on large orthocones including data and materials from the eastern Amessoui Syncline.
KLUG et al. (2015b): Book chapter on methods of ammonoid description depicting specimens from the eastern Amessoui Syncline.
NAGLIK et al. (2015a, b, 2016): Studies on ontogeny and hydrostatic properties of Middle Devonian ammonoids based on grinding tomography data from Moroccan specimens including such from the Amessoui Syncline.
HARTENFELS & BECKER (2016b online): Conodonts and ammonoids of the late Famennian from various sections including Jebel Ouaoufilal.
KLUG (2017): A review of the ammonoid stratigraphy of the early Emsian in the Tafilalt.
KORN & BOCKWINKEL (2017): Several new species of *Gonioclymenia* including specimens from the eastern Amessoui Syncline.
POHLE & KLUG (2018): Quantitative study of body size of cephalopods with orthoconic conchs throughout the Devonian, largely based on material and measurements from the Amessoui Syncline.

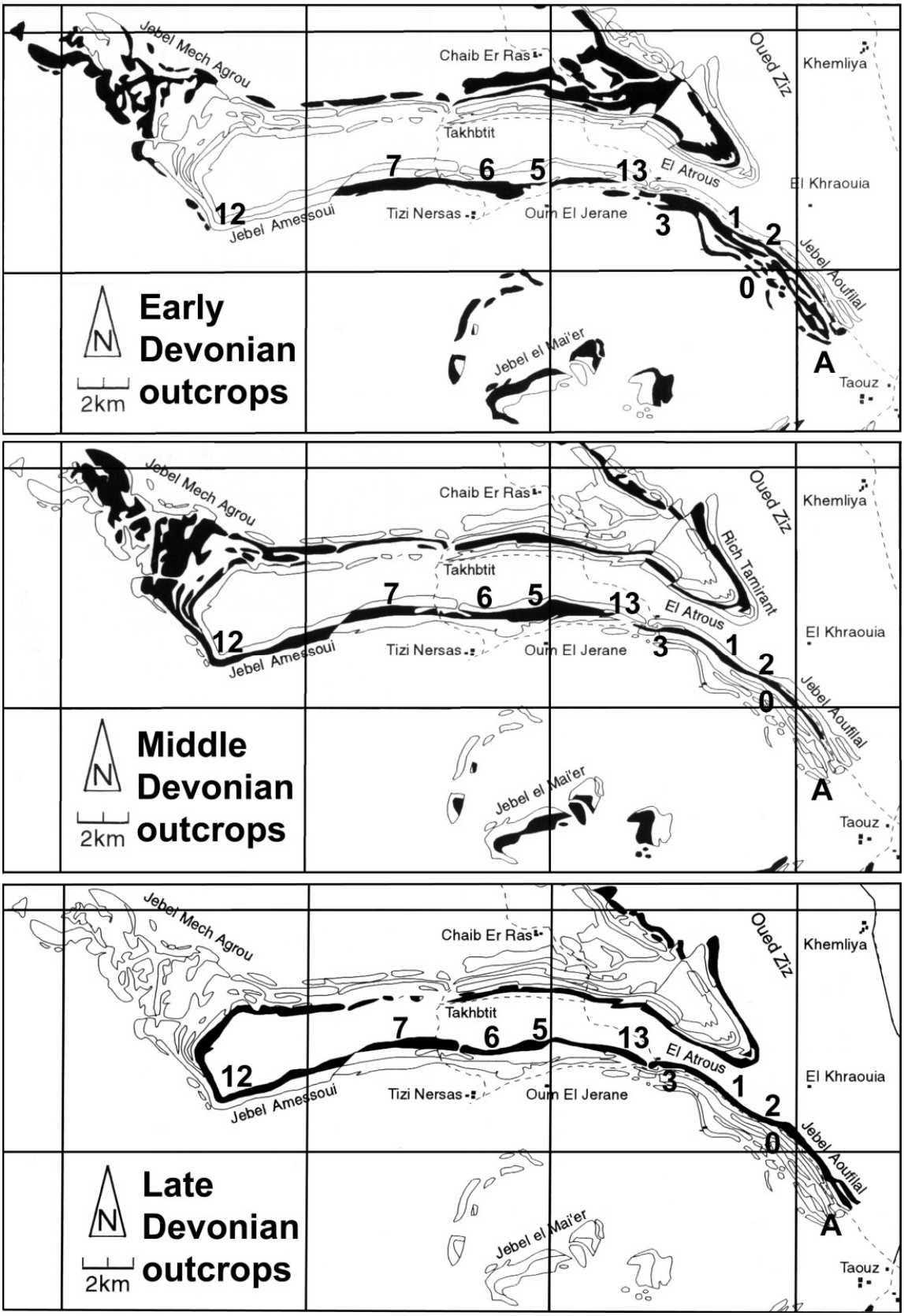

Fig. 3: Outcrops of Early, Middle and Late Devonian sediments in the Amessoui Syncline (modified after KLUG et al. 2013) and localization of the sections (numbers in bold) shown in other figures below.

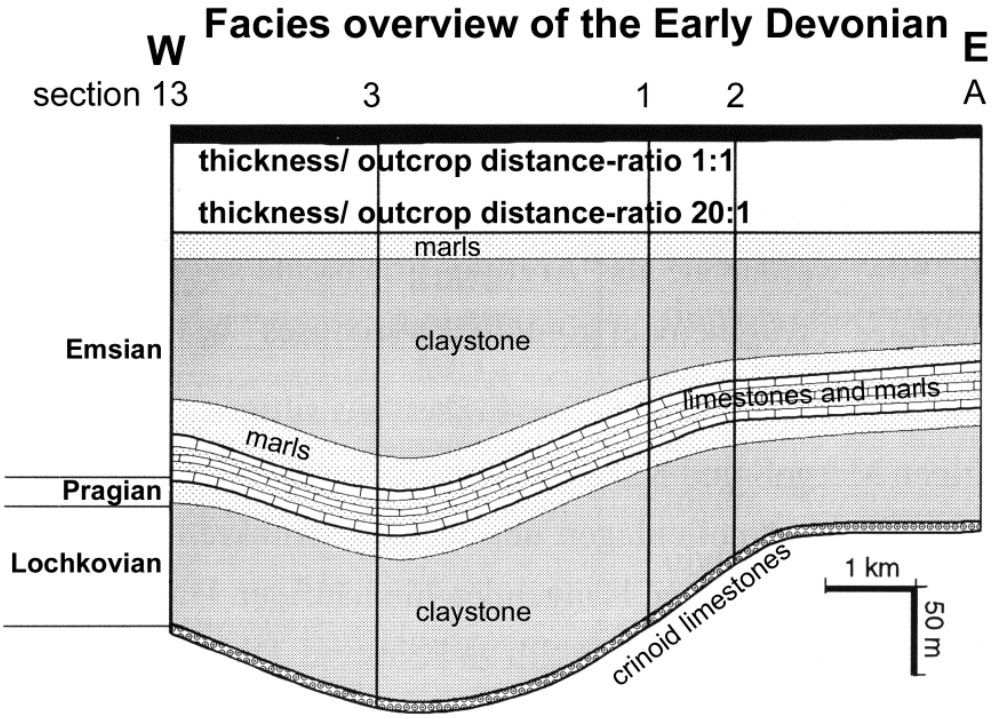

Fig. 4: Sketch of the distribution of lithofacies in the eastern Amessoui Syncline during the Early Devonian. The black bar represents the thickness distribution in the correct scale to the distance on the surface. For the localization of the sections (numbers above the black bar) see Fig. 3.

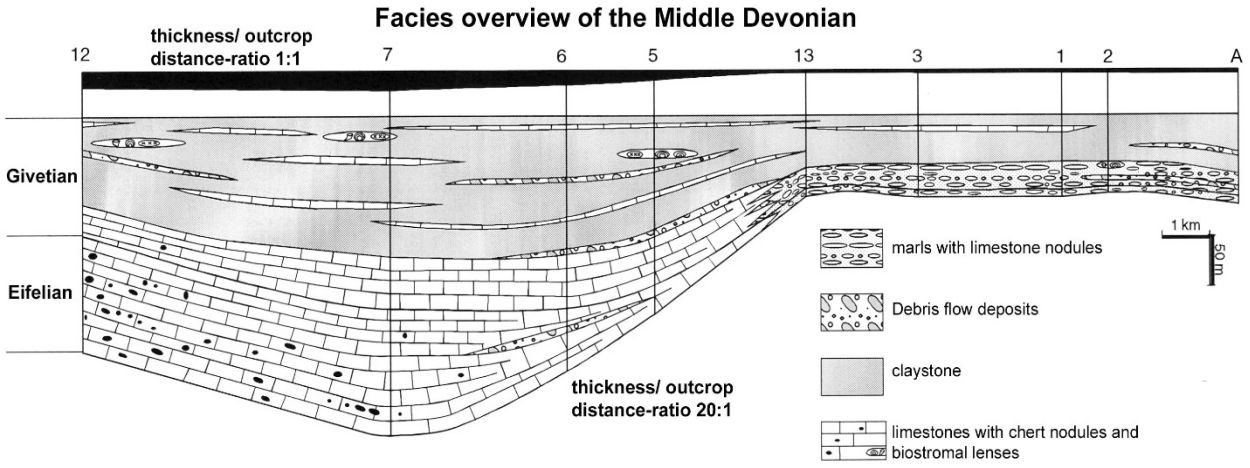

Fig. 5: Sketch of the distribution of lithofacies in the eastern Amessoui Syncline during the Early Devonian. The black bar represents the thickness distribution in the correct scale to the distance on the surface. For the localization of the sections (numbers above the black bar) see Fig. 3.

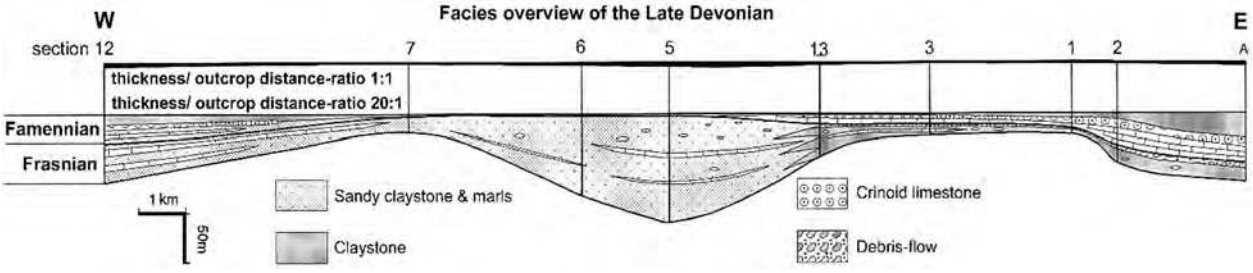

Fig. 6: Sketch of the distribution of lithofacies in the eastern Amessoui Syncline during the Late Devonian. The black bar represents the thickness distribution in the correct scale to the distance on the surface. For the localization of the sections (numbers above the black bar) see Fig. 3.

3. Palaeogeographic setting

As mentioned above, a marine basin and pelagic ridge-system developed in the course of the Devonian (WENDT et al. 1984; WENDT 1985, 1988; BAIDDER et al. 2016). During the Silurian and Early Devonian, this topography was not fully established yet (Fig. 4). KAUFMANN (1998) published isopach maps for the Early, Middle, and Late Devonian that show this increasing differentiation in sedimentary thickness, reflecting the developing basins and elevations.

The Amessoui Syncline is interesting for sedimentologists because the transition from the eastern slope of the Maïder Basin via the southern Tafilalt Platform into the upper slope to the Tafilalt Basin in the East is well exposed, particularly on the southern flank of the syncline. Facies developments and thickness distribution of the Middle and Late Devonian sequences are depicted in Figs. 5 and 6.

4. Sedimentary succession and cephalopod faunas

4.1. Silurian

The Silurian sedimentary sequence is rather clay-dominated (BELKA et al. 1999; BECKER et al. 2013). This is probably the reason why these sediments were regionally sheared off tectonically along major thrust faults, which surface usually at the southern edge of the synclines in the Tafilalt (BAIDDER et al. 2016). The claystones usually have a rather dark colour when they are fresh, but mostly, the weathered sediments are pinkish due to surficial weathering. The geomorphologically most conspicuous stratum is the ***Temperoceras* Limestone**, which is of Ludfordian age (KRÖGER 2008). These limestones are of regional economic importance because the beautiful black limestones are full of white cephalopods with black septa, yielding aesthetic surfaces when polished. KRÖGER (2008) listed the following cephalopod genera from this interval: *Arionoceras*, *Hemicosmorthoceras*, *Kionoceras*, *Kopaninoceras*, *Michelinoceras*, *Parasphaerorthoceras*, *Plagiostomoceras*, *Sphooceras* (?), *Subormoceras*, and *Temperoceras*.

The Pridolian is also dominated by limestones with a few black orthocerid-limestone nodules, particularly towards the Silurian-Devonian boundary. Immediately below the boundary, the world-famous ***Scyphocrinites* Limestone** is situated. In the Amessoui Syncline, it is full of large loboliths (e.g. FREY et al. 2014) as well as other, more or less articulated remains of *Camarocrinus*, platyceratid gastropods, bivalves, and some orthocerids (Figs. 5, 7, 8).

4.2. Lochkovian

Above the *Scyphocrinites* Limestone, the carbonate content (MASSA 1965) quickly declines. Much of the Lochkovian sequence is composed of claystones, occasionally with graptolites and a few layers with limestone nodules that bear orthocerids (FREY et al. 2014). In a fresh state, these claystones and limestones are black, suggesting low oxygen conditions at the sea-floor. In the eastern Amessoui Syncline, there are two conspicuous nodule-levels, the lower level contains abundant *Plagiostomoceras culter*, while the upper level is richer in carbonate and mainly yields *Temperoceras* and *Adiagoceras* (KRÖGER 2008).

Fig. 7: Columnals and calyx plates of *Camarocrinus* from the latest Silurian of Filon 12 (*Scyphocrinites* Limestone).

Towards the top of the Lochkovian part of the section, the carbonate content increases, the colour of the sediments changes from dark to light grey, and the proportion of benthic faunal elements increases (BELKA et al. 1999; FREY et al. 2014).

4.3. Pragian

The increase in oxygen-content in the **Pragian Limestone** (FREY et al. 2014) is reflected in the great diversity of benthic organisms, although infaunal elements are still rare. Apparently, cephalopods also profited from the higher oxygen levels. FREY et al. (2014) listed the following cephalopod genera from the 'Pragian': *Arionoceras*, *Arthrophyllum*, *Bohemojovellania*, *Endoplectoceras, Plagiostomoceras*, *Pseud-enplectoceras*, *Spyroceras*, *Temperoceras,* and *Tafilaltoceras*.

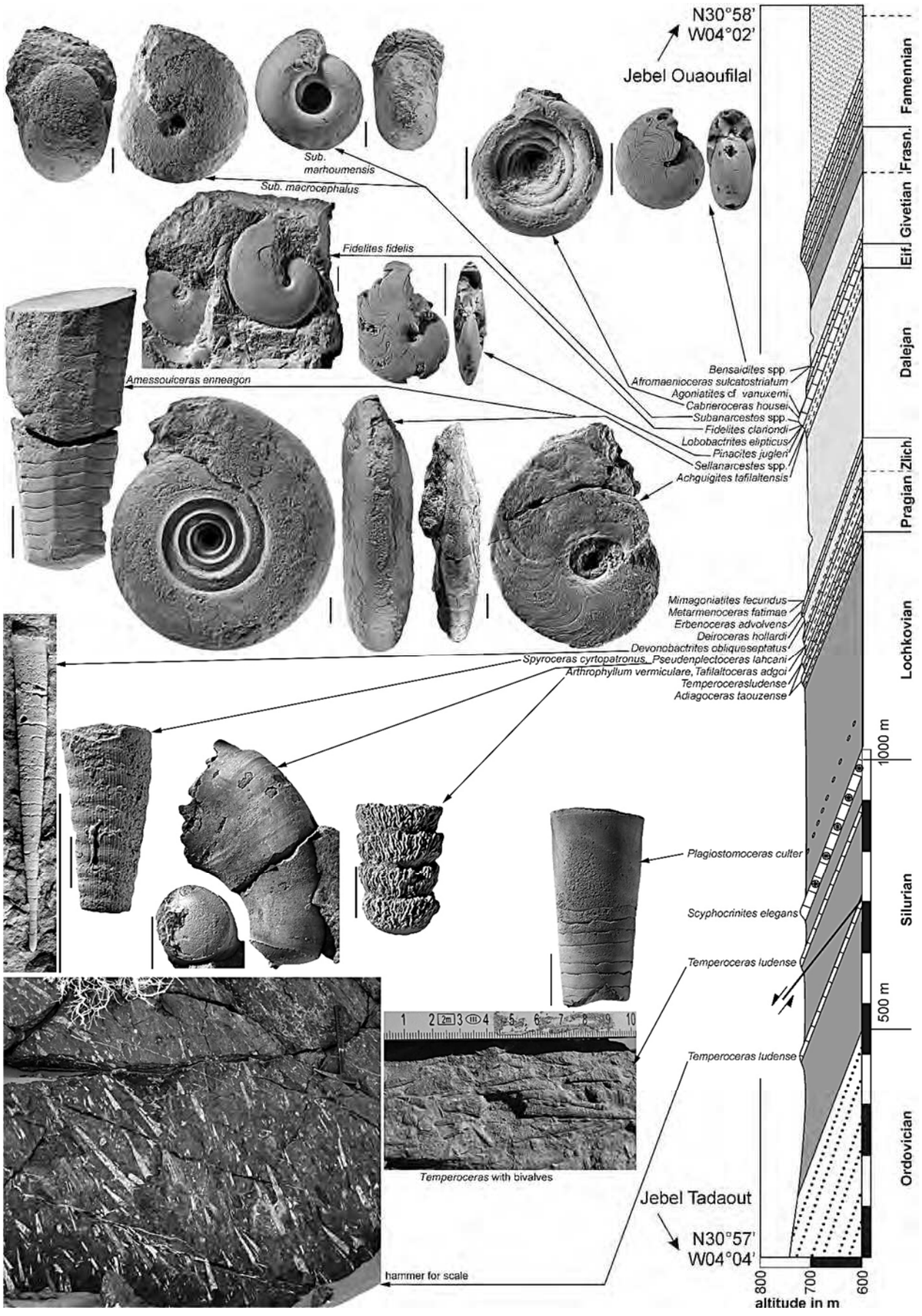

Fig. 8: Section from Filon 12 towards El Khraouia/Jebel Ouaoufilal through the Palaeozoic sedimentary succession (modified after FREY et al. 2014). On the left, important cephalopods of early Ludfordian to early Givetian age are depicted (modified from KLUG 2002a, using photos from KORN & KLUG 2002, KLUG et al. 2010b, and FREY et al. 2014).

4.4 Emsian

The Emsian still is the longest stage of the Devonian, which is nicely reflected in the great sedimentary thickness of the corresponding interval in the Amessoui Syncline (Fig. 4). Above the Pragian marls, a succession of greenish claystones follows, which yields a rich, largely haematitized fauna (Fig. 9) that was dubbed Faunule 1 (KLUG et al. 2008; DE BAETS et al. 2010a; ABOUSSALAM et al. 2015). According to the most common fossil, the interval was also termed ***Devonobactrites*** **Shale** (ABOUSSALAM et al. 2015). From this interval, KLUG et al. (2008) documented the cephalopod genera *Archiacoceras*, *Arthrophyllum*, *Chebbioceras*, *Devonobactrites*, *Infundibuloceras*, *Orthocycloceras*, *Temperoceras*, and *Trochoceras*.

Fig. 9: Faunule 1 from the *Devonobactrites* Shale near Filon 12. There are several haematitic specimens of *Devonobactrites*, a hyolithid, and a couple of palaeotaxodont bivalves (*Phestia*, *Nuculoidea*). Approximately natural size.

In the eastern Amessoui Syncline, these shales are capped by the massive ***Deiroceras*** **Limestone** (ABOUSSALAM et al. 2015; KRÖGER 2008), which contains large representatives of *Deiroceras* and also orthocerids (Fig. 10).

A second claystone interval (***Metabactrites-Erbenoceras*** **Shale**) follows above the *Deiroceras* Limestone. In other parts of the Tafilalt, this interval yields the diverse **Faunule 2** (KLUG 2001; KLUG et al. 2008; DE BAETS et al. 2010a; ABOUSSALAM et al. 2015), which contains some of the oldest ammonoids, although usually fragmentary. In the Amessoui Syncline, these shales are poorly exposed and rarely yield cephalopod remains.

The overlying ***Erbenoceras*** **Limestone** or ***Anetoceras*** **Limestone** (HOLLARD 1963; KLUG 2001; KLUG et al. 2008; KRÖGER 2008; DE BAETS et al. 2010a; ABOUSSALAM et al. 2015) contains usually poorly preserved remains of the ammonoids *Anetoceras*, *Erbenoceras*, *Klugites, Teicherticeras,* and *Weyeroceras*. Additionally, moderately sized bactritids and orthocerids co-occur.

Fig. 10: Large orthocerid in the *Deiroceras* Limestone (early Emsian) near Filon 12 (Swiss army knife for scale: 85 mm long).

These limestones grade into the ***Mimagoniatites*** **Limestone** (HOLLARD 1963; WALLISER 1991; ABOUSSALAM et al. 2015), which is more marly and contains less ammonoids. In the Amessoui Syncline, there is one black marker bed (a crinoid limestone) and the top of the more limy marls bears poorly preserved specimens of the index ammonoid *Mimagoniatites fecundus* (KLUG 2001) as well as giant specimens of the actinocerid *Deiroceras hollardi* (Fig. 11). Some phragmocones exceed 1 m in length and according to some estimates, the entire conchs may have reached nearly 3 m in length with septa reaching almost 300 mm across (KLUG et al. 2015a; POHLE & KLUG 2018).

The following lithostratigraphic unit, the late Emsian **Daleje Shales**, can reach thicknesses of about 100 m in the eastern Anti-Atlas (KAUFMANN 1998). In the eastern Amessoui Syncline, it is often covered by scree and poor in fossils. Occasionally, phacopid trilobites, small rugose corals or haematitic internal moulds of ammonoids and orthocerids can be found.

Towards the top of the Daleje Shales, the carbonate content increases (MASSA 1965). These marls are the so-called ***Anarcestes*** **Limestone** (ABOUSSALAM et al. 2015) or ***Sellanarcestes*** **Limestone** (BULTYNCK & WALLISER 2000). Near Filon 12, these strata are rich in ammonoids and other cephalopods as well as benthic fauna (brachiopods, corals, crinoids, gastropods, ostracods, trilobites, etc.). In the lower part of the *Anarcestes* Limestone, where the term *Sellanarcestes* Limestone would actually suit better,

Achguigites and *Sellanarcestes* are the most common ammonoid genera (KLUG 2002). A little higher in the section, *Sellanarcestes* vanishes and *Anarcestes* dominates. Near the Emsian/Eifelian boundary, ammonoids are quite rare. There, rare large specimens of *Mimagoniatites bohemicus* and the coiled spiny nautiloid *Hercoceras* were found (KLUG 2002; unpublished data).

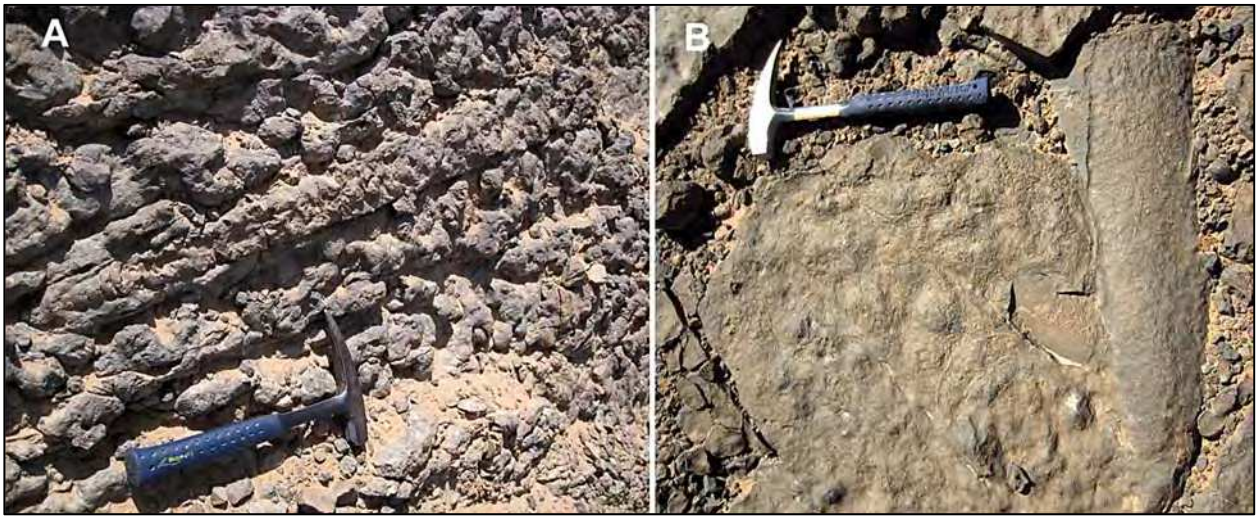

Fig. 11: Large actinocerids (*Deiroceras hollardi*) in the *Mimagoniatites* Limestone (early Emsian) near Filon 12 (hammer for scale: 300 mm long). **A.** Specimen is 1250 mm long; note the siphuncle on the left. **B.** Two big fragments, both 200 mm wide.

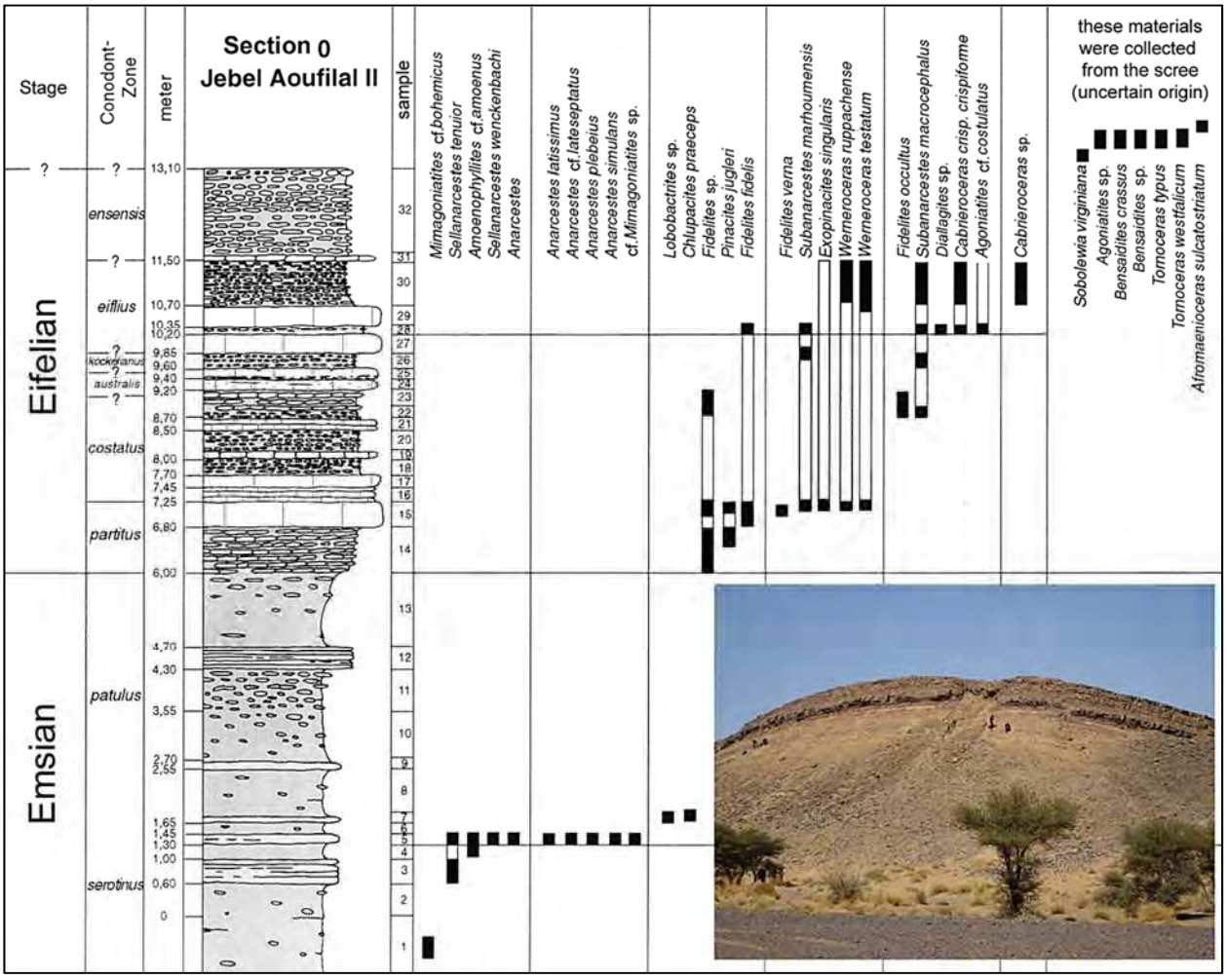

Fig. 12: Late Emsian to Eifelian succession with ammonoid content. The Givetian fauna was collected loosely in the next valley.

4.5. Eifelian

Between Filon 12 and El Khraouia (section in Fig. 12), the Eifelian succession is particularly rich in ammonoids (KLUG et al. 2000; KLUG 2002a, b) and hardly exploited by fossil dealers, probably because the fossils are not so attractive for tourists. The sedimentary succession begins with an increase in carbonate content from yellowish marls via light grey nodular limestones and dark grey nodular limestones into massive limestone beds (1 m thick), which is full of cephalopods and often shows haematite crusts parallel to bedding (condensation; KLUG et al. 2013).

The dark grey nodular limestones were probably deposited after the **Choteč-Event** ("*jugleri* Event" after Pinasensu WALLISER 1985; REQUADT & WEDDIGE 1978; CHLUPÁČ 1985; BERKYOVA & MUNNECKE 2010; KOPTÍKOVÁ 2011). These styliolinid packstones contain many specimens of the ammonoids *Fidelites*, *Pinacites,* as well as orthocerids, bivalves, and occasional phacopid trilobites. The massive limestones above (*Pinacites jugleri* Zone) are extremely rich in cephalopods, such as the bactritid *Lobobactrites*, the ammonoids *Fidelites clariondi*, *Pinacites jugleri*, *Subanarcestes marhoumensis*, and *Werneroceras*, as well as the 'nautiloids' *Arionoceras*, *Capricornites*, *Conostichoceras*, *Geisonoceras*, *Paracleistoceras*, *Spyroceras*, and *Suloceras*.

Due to a slight increase in clay content, bedding becomes finer above and the layers are a bit more deeply eroded (about 2.3 m). The fossil content is still high (Fig. 12), although ammonoid diversity appears to be a bit reduced. In these strata, we found the ammonoids *Subanarcestes macrocephalus*, *Diallagites testatum*, *Exopinacites singularis*, and *Wendtia ougarta*, as well as the 'nautiloids' *Cerovoceras*, *Paracleistoceras*, and *Spyroceras*.

Above, two thicker limestone layers follow. These are locally extremely rich in cephalopods (Fig. 13). As far as ammonoids are concerned, there are predominantly *Agoniatites vanuxemi*, *Cabrieroceras housei*, *Diallagites testatum*, *Exopinacites singularis, Sobolewia* sp., *Subanarcestes coronatus,* and *Sub. sphaeroides*. Specimens of *Agoniatites*, *Cabrieroceras,* and *Exopinacites* sometimes reach conch diameters of almost 300 mm. The same strata yield a wealth of 'nautiloids' belonging to the genera *Aphyctoceras*, *Apioceras, Arionoceras*, *Brevicoceras*, *Capricornites*, *Conostichoceras*, *Gonatocyrtoceras,* and *Moneroceras*.

With the declining carbonate content, cephalopod diversity also declines in the overlying layers. Probably, this rise in clay content correlates with the **Kačák Event** ("*otomari*" and "*rouvillei*" Events *sensu* WALLISER 1985; HOUSE 1985, 1989, 1993; SCHÖNE 1997; "Great Gap", "Late Eifelian Events 1 + 2", "Odershausen Events" (WEDDIGE 1988, 1996; WEDDIGE & STRUVE 1988). This event corresponds to a sea-level rise (HAQ & SCHUTTER 2008). Although poorer in ammonoids, specimens of the ammonoid genera *Agoniatites*, *Cabrieroceras*, *Parodiceras,* and *Wedekindella* can be found occasionally. They are accompanied by small orthocerids, which we have not determined yet.

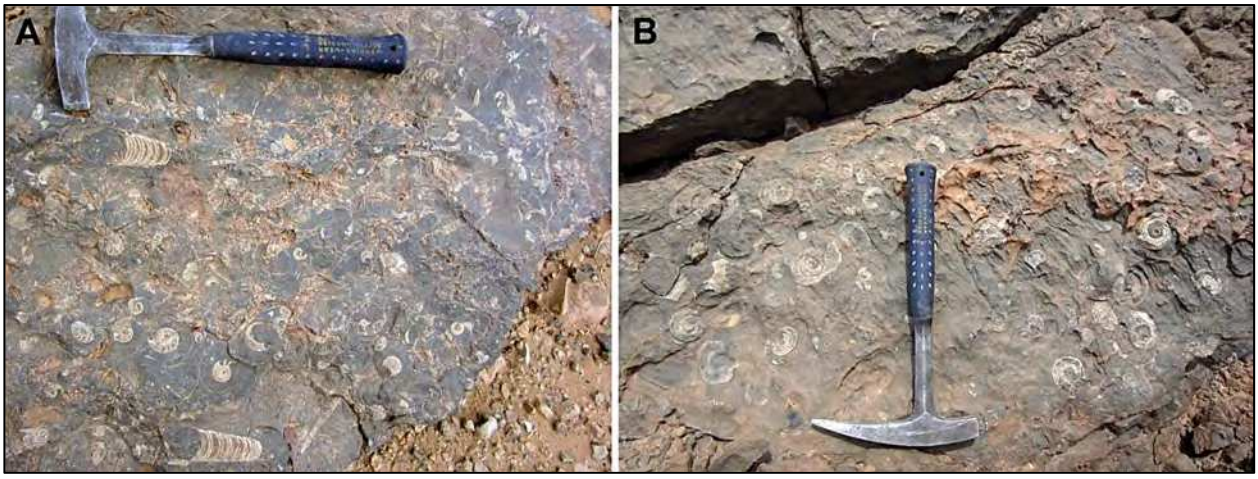

Fig. 13: Late Eifelian limestones with abundant specimens of the ammonoid genera *Agoniatites*, *Cabrieroceras,* and *Subanarcestes* as well as common orthocerids (hammer for scale: 300 mm long).

4.6. Givetian

The Middle Devonian sequence continues with beds of strongly varying thickness and clay content. Rapid lateral facies changes were probably caused by mass movements from the Tafilalt Platform towards the Tafilalt Basin (Fig. 14). The strata around the Eifelian Givetian boundary are usually poor in cephalopods. Occasionally, remains of orthocerids or the ammonoid *Agoniatites* can be found. Still within the early Givetian, carbonate content decreases strongly (MASSA 1965). The thick claystone sequence is usually deeply eroded, forming a valley. The base of these claystones (Fig. 13 top) yields a haematitic fauna with abundant phragmocones of the ammonoid *Bensaidites,* accompanied by rarer *Afromaenioceras*, *Agoniatites*, *Sobolewia*, orthocerids, bivalves, and gastropods. Sediments of the late Givetian are rarely exposed in this part of the Amessoui Syncline.

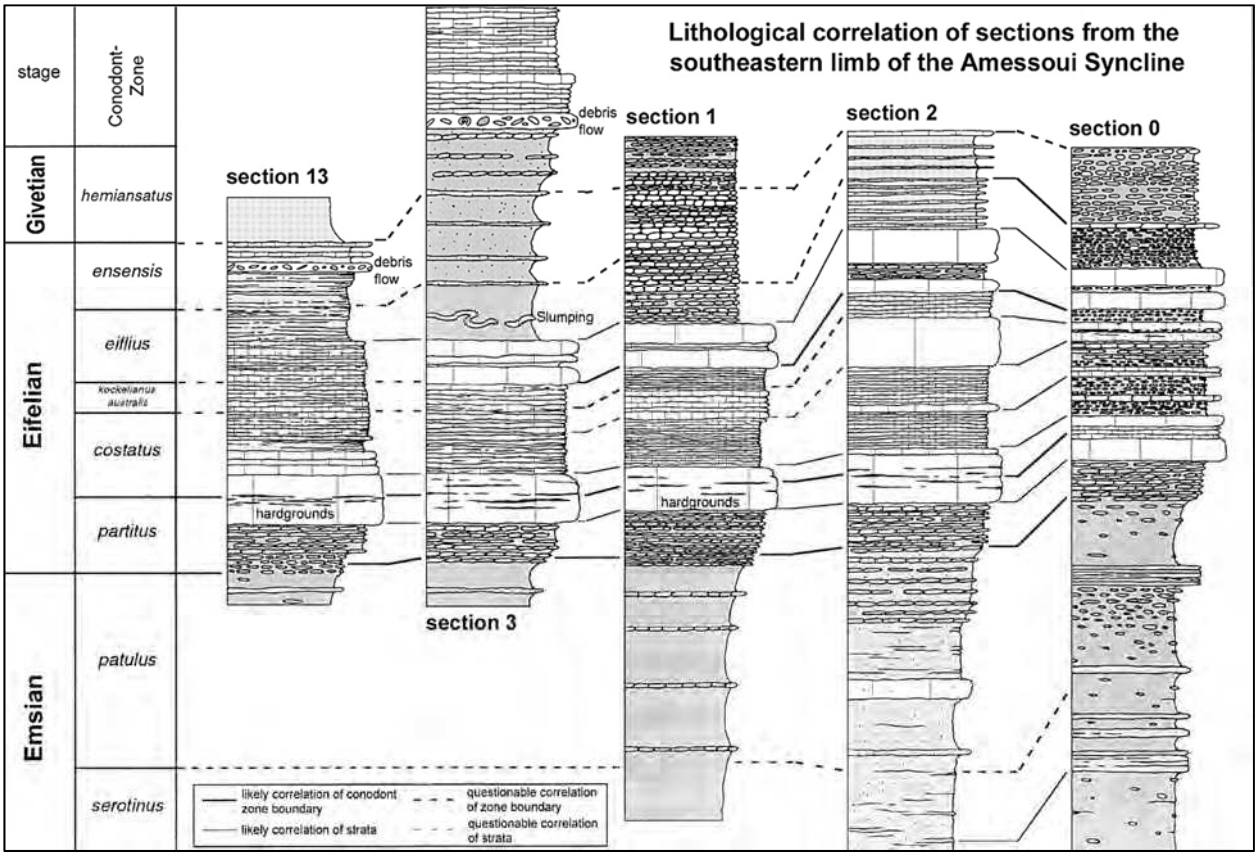

Fig. 14: Correlation of five sections from the southeastern limb of the Amessoui Syncline. Note the lateral facies changes in the late Eifelian and early Givetian, where slumping and debris flows with shallow water fauna (corals, stromatoporoids, brachiopods) occur. Scale: The thick limestone at the *partitus-costatus* conodont Zone boundary is 1 m thick.

4.7. Frasnian

Between Filon 12 and El Khraouia, the Frasnian is almost as poorly exposed as the Givetian. However, two important event intervals can be seen in most outcrops, namely equivalents of the global **Frasnes Events** and the **Kellwasser Interval** (Fig. 1). The Frasnian sediments contain some ammonoids, such as beloceratids and manticoceratids.

4.8. Famennian

The Famennian is again much better exposed and yields many different cephalopod taxa. The basal Famennian consists of thin-bedded sandy limestones with occasional concretions containing *Phoenixites frechi*. These layers are covered by a more clayey interval (**Condroz Events** *sensu* BECKER 1993) that again contains thin limestone layers with concretions that may yield ammonoids (cheiloceratids; Fig. 15), placoderms (mainly *Dunkleosteus*), and rarely crinoid colonies (*Moroccocrinus*).

The late early to late Famennian succession contains some more massive limestone layers, which were documented in greater detail by KORN et al. (2000). A general increase in thickness from west to east, i.e. towards the Tafilalt Basin is conspicuous. This can best be seen when examining the massive crinoid limestones that increase from 1 m at Oum El Jerane to over 5 m near section A (Fig. 3). At the top of these massive limestones, thinner highly

condensed cephalopod beds follow (Fig. 16). Between El Atrous and Taouz, these beds contain haematite crusts, sometimes with a stromatolitic appearance (*Frutexites*). Above, a thin black nodular limestone layer occurs locally, which is rich in clymeniids (*Cyrtoclymenia, Platyclymenia, Prionoceras*) and orthocerids (KORN et al. 2000; HARTENFELS 2011; HARTENFELS & BECKER 2016a). These limestones are overlain by a fossiliferous claystone sequence. The thickness of these claystones increases from 0 to 8 m from El Atrous to section A. These claystones are capped by the last conspicuous limestone marker bed, the ***Gonioclymenia* Limestone** (HARTENFELS & BECKER 2016b; KORN & BOCKWINKEL 2017). This layer is usually 200 to 400 mm thick and has largely been exploited by locals for the beautifully preserved and colourful specimens of various species of *Gonioclymenia*, which reach diameters of over 400 mm. The subsequent claystone unit also contains ammonoids and other cephalopods, commonly preserved as haematitic internal moulds, which weather out of the sediments and accumulate on the surface. From these sediments, we collected specimens of the ammonoid genera *Alpinites*, *Balvia*, *Cymaclymenia*, *Cyrtoclymenia*, *Discoclymenia*, and *Mimimitoceras*.

Due to the uniform sedimentary facies (mostly claystones with thin siltstone beds) and the extreme scarcity of ammonoids in situ, it is hardly possible to exactly place the Devonian-Carboniferous boundary in this region.

Fig. 15: Haematitized internal mould of an early Famennian ammonoid in limestone, between Filon 12 and El Khraouia.

Fig. 16: Large clymeniid, two orthocerids, and crinoid roots (left) on a bedding plane of an iron-stained limestone of the *Platyclymenia annulata* Zone; in the Ziz Valley, just west of Taouz and south of Jebel Ouaoufilal.

4.9. Tournaisian

On the southeastern limb of the Amessoui Syncline, the Tournaisian succession is composed of fine clastic sediments varying between claystones, siltstones, and fine-grained sandstones. Occasional body fossils and trace fossils provide evidence for lasting marine conditions, although possibly rather shallow as suggested by numerous levels with wave ripples. Between Jebel Ouaoufilal and Filon 12, some thin sandstone layers contain a moderately diverse ichnofauna (Fig. 17). Because of the abundance of traces like *Asteriacites* and *Rusophycus*, we interpret this assemblage as *Cruziana* ichnofacies.

Above these sandstone layers, grain size decreases again and the outcrop quality deteriorates towards the village of El Khraouia. One last layer is worth mentioning. El Khraouia is situated on a low plateau that overlooks the Ziz Valley towards the northeast (the dunes of Erg Chebbi as well as the Algerian Hamada du Guir are visible in the distance). On this plateau around the houses, the inhabitants found two highly diverse haematitic faunas comprising mainly ammonoids and rare trilobites (KORN et al. 2003). This fauna yielded representatives of the ammonoid genera *Becanites*, *Eurites*, *Helicocyclus*, *Irinoceras*, *Muensteroceras*, *Ouaoufilalites*, *Pericyclus*, *Progoniatites*, *Triimitoceras*, and *Winchelloceras*. With this locality, the Palaeozoic succession ends at this place.

Fig. 17: Ichnofauna (*Cruziana* ichnofacies) and sediment structures of the Tournaisian south of El Khraouia. **A.** Tool marks and trace fossils; **B.** *Asteriacites* (bottom left) and other traces; **C.** *Asteriacites* cf. *guglhupf*, surrounded by other traces; the broadly curved one might be a trace from the fins of a fish; **D.** Arthropod resting trace (cf. *Rusophycus*, probably not of trilobite origin) and walking trace; swiss army knife for scale (85 mm long).

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